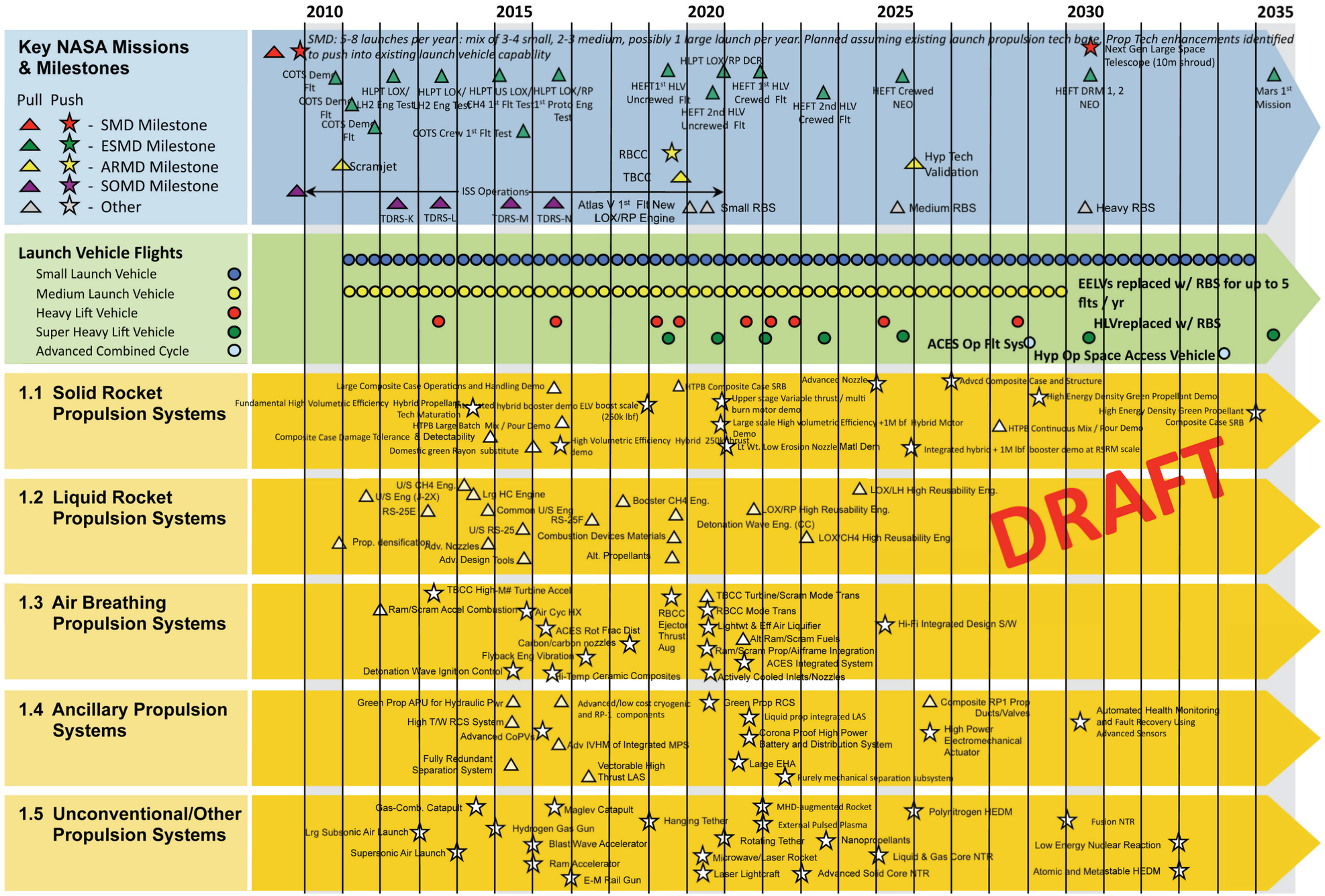
SPACE TECHNOLOGY ROADMAPS • STR

FOR THE FOURTEEN TECHNOLOGY AREAS

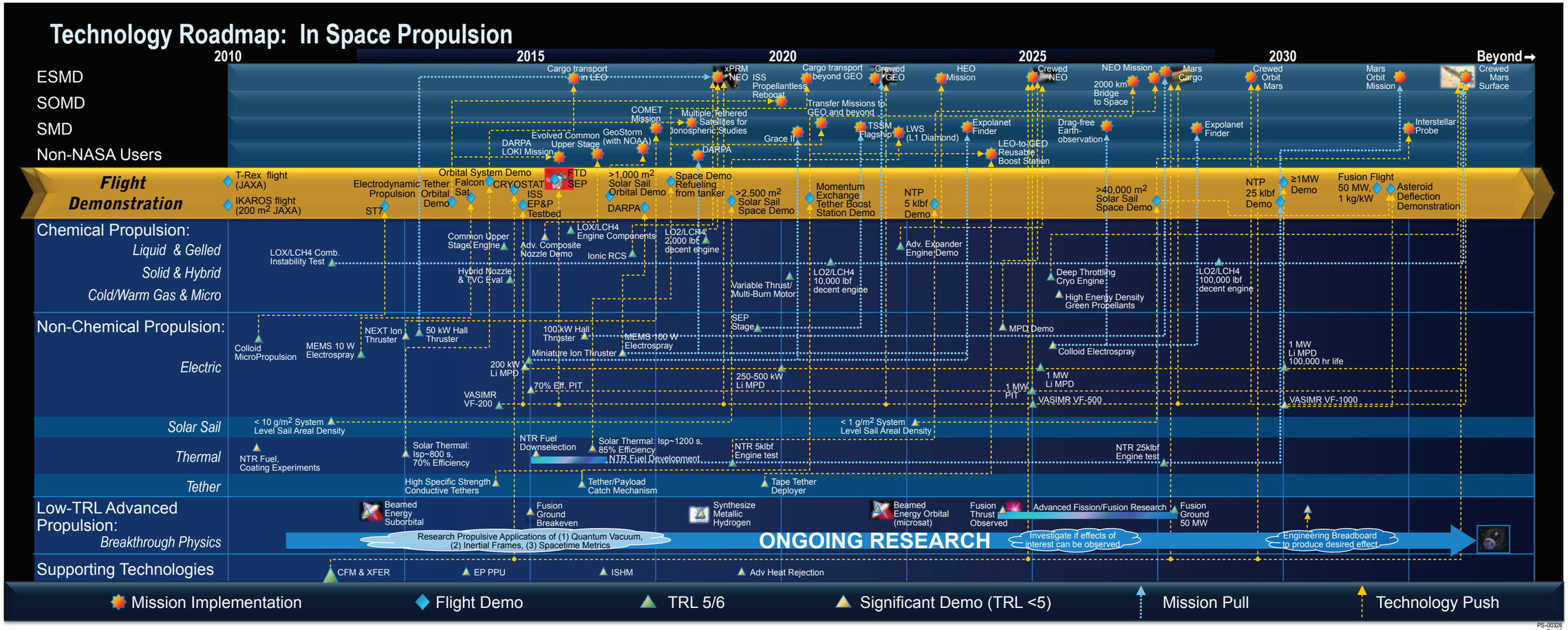
TECHNOLOGY AREA STRATEGIC ROADMAPS (TASR)

TECHNOLOGY AREA BREAKDOWN STRUCTURE (TABS)

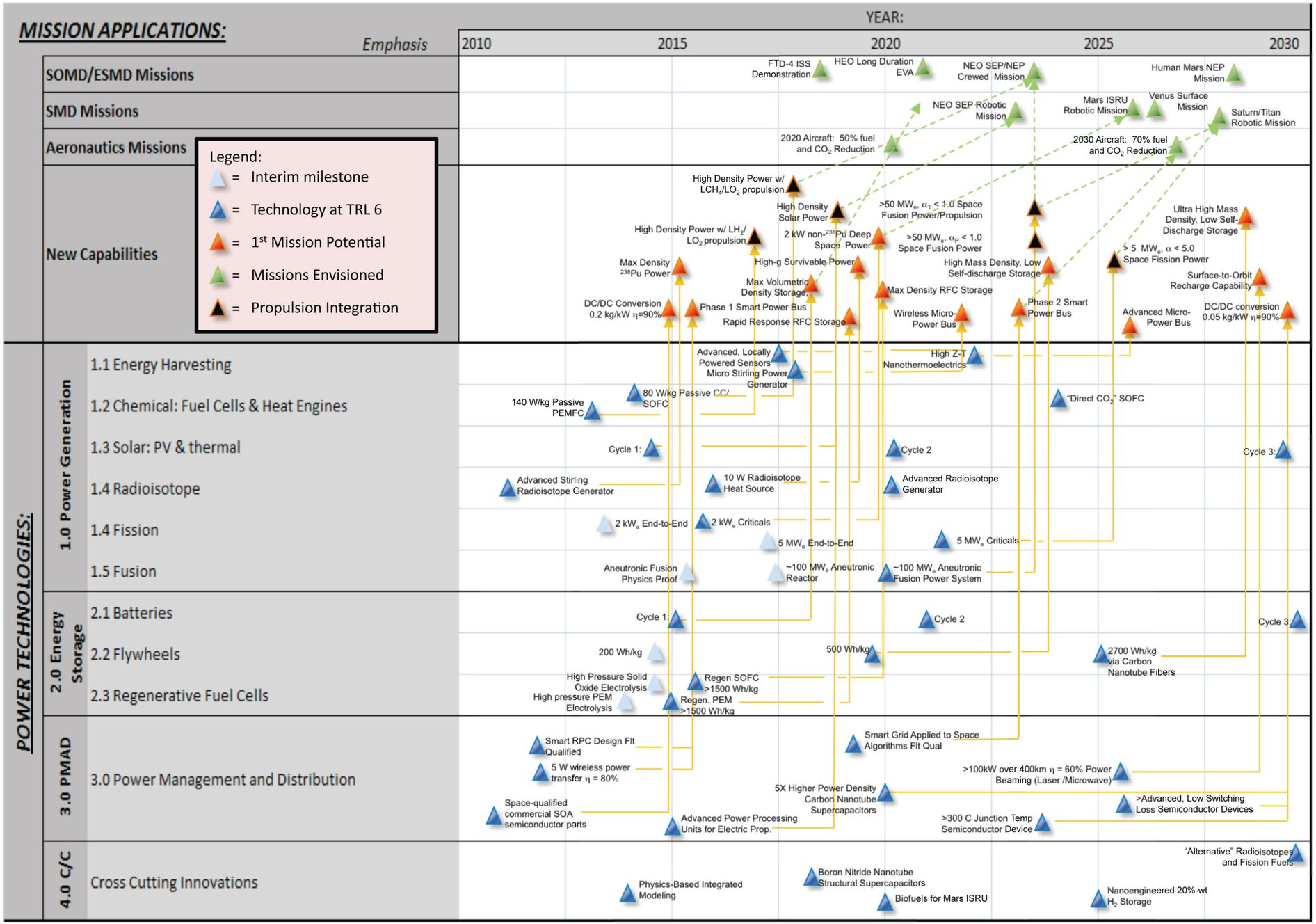
Technology Area 01: *Launch Propulsion Systems Technology Area Strategic Roadmap (TASR).*



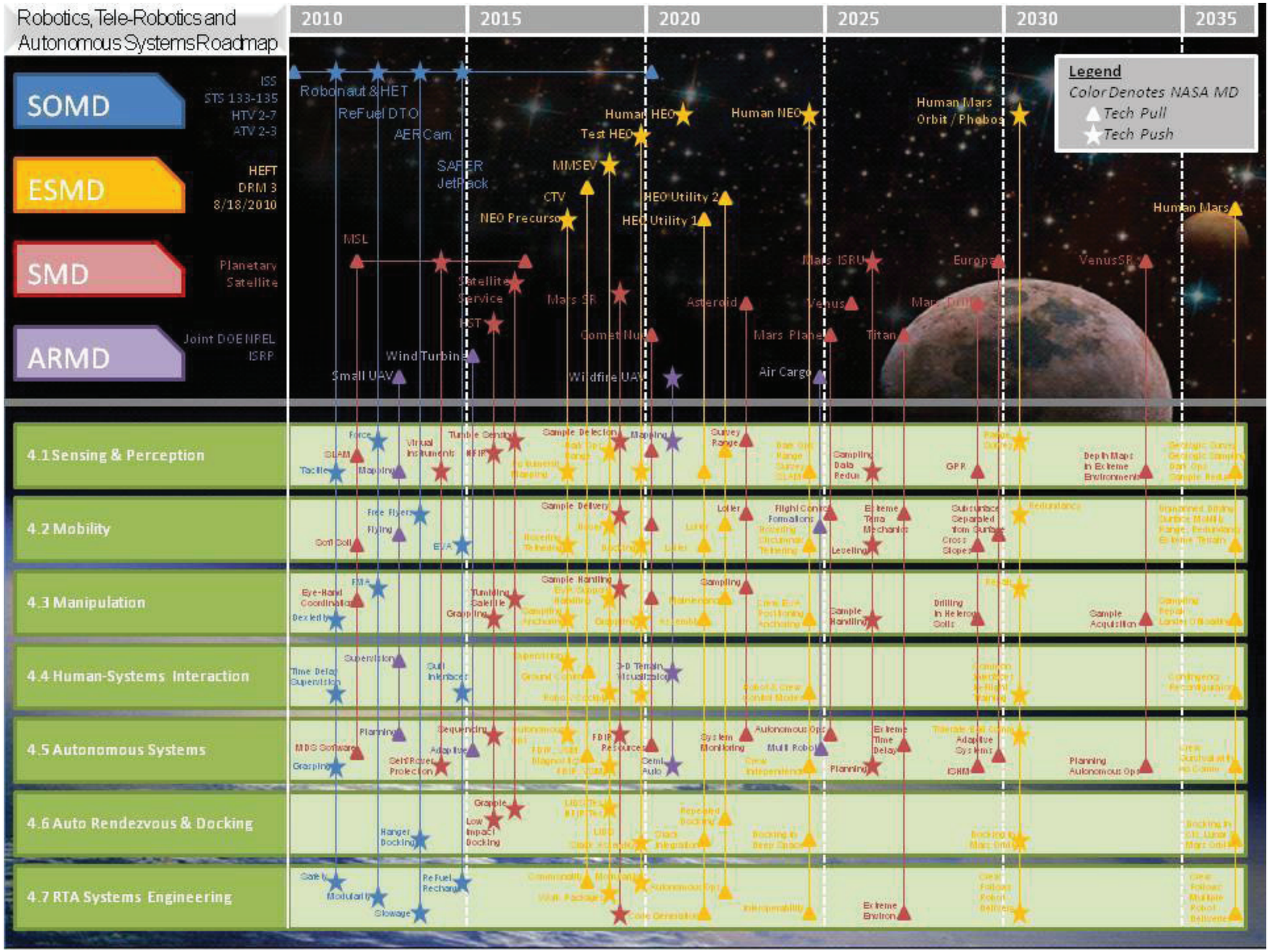
Technology Area 02: *In Space Propulsion Technology Area Strategic Roadmap (TASR)*



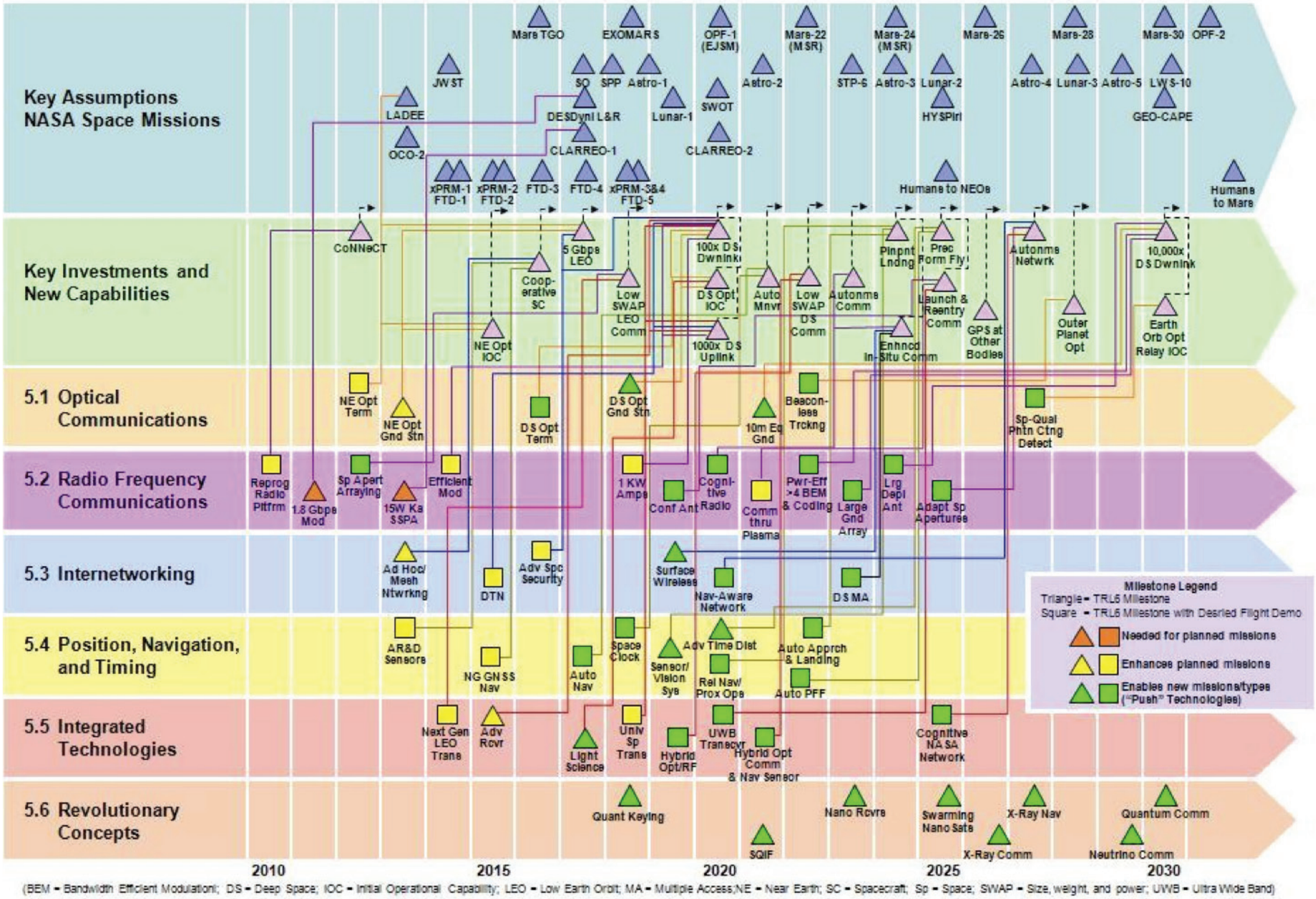
Technology Area 03: *Space Power and Energy Storage Roadmap*



Technology Area 04: *Robotics, Tele-Robotics and Autonomous Systems Technology Area Strategic Roadmap (TASR)*

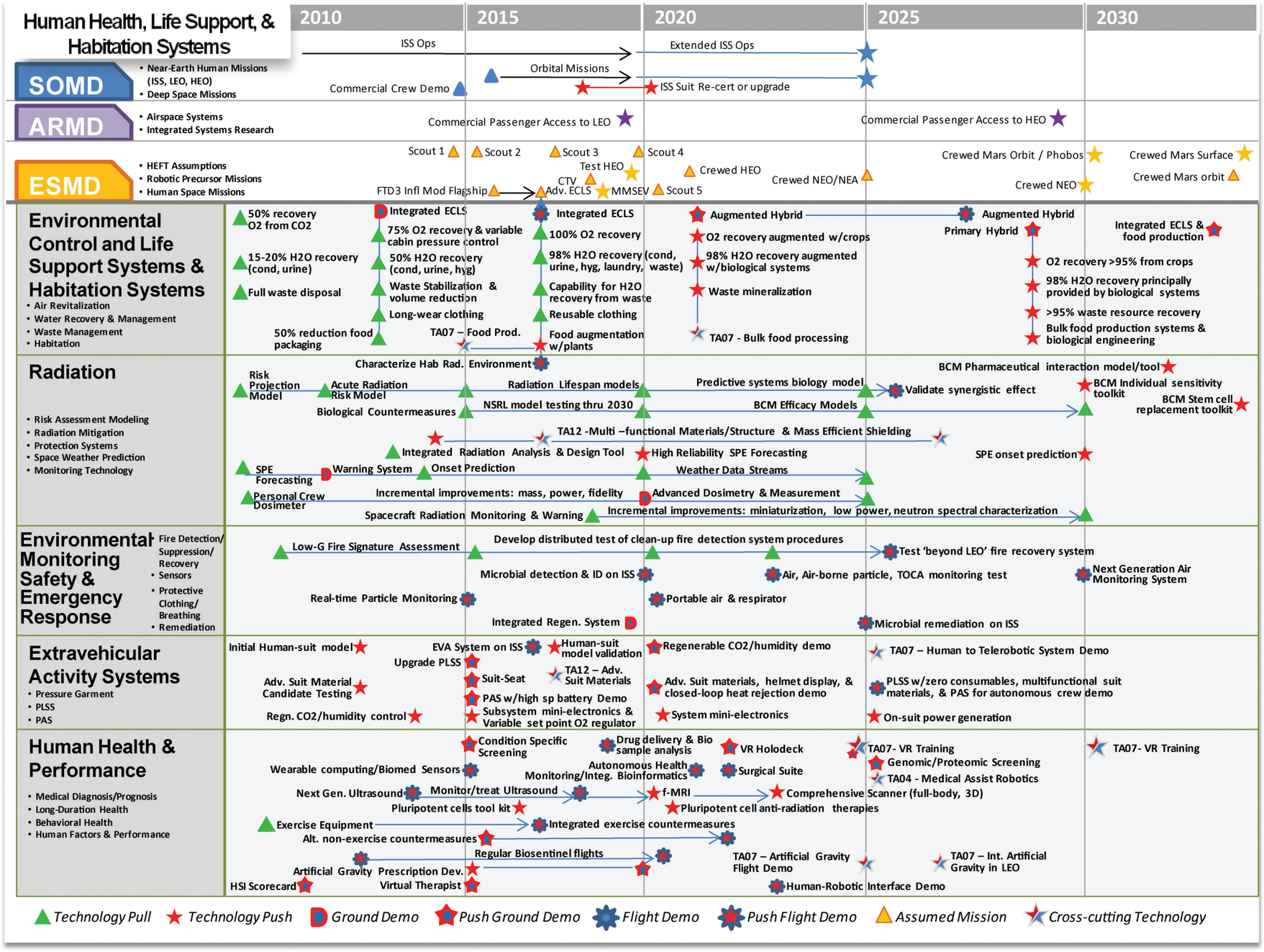


Technology Area 05: *Communication and Navigation Systems Technology Area Strategic Roadmap (TASR)*



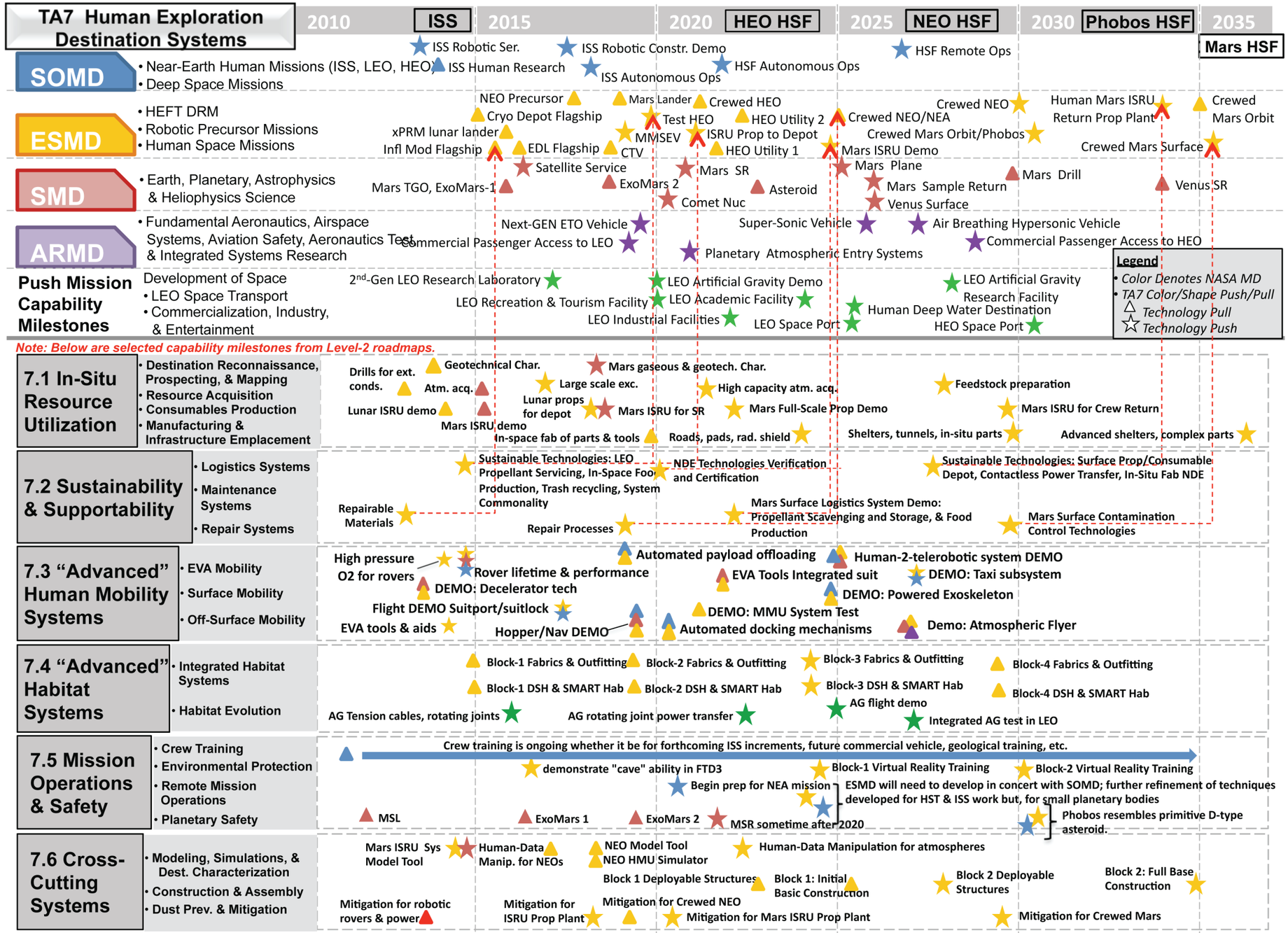
(BEM = Bandwidth Efficient Modulation; DS = Deep Space; IOC = Initial Operational Capability; LEO = Low Earth Orbit; MA = Multiple Access;NE = Near Earth; SC = Spacecraft; Sp = Space; SWAP = Size, weight, and power; UWB = Ultra Wide Band)

Technology Area 06: *Human Health, Life Support and Habitation Systems Roadmap*

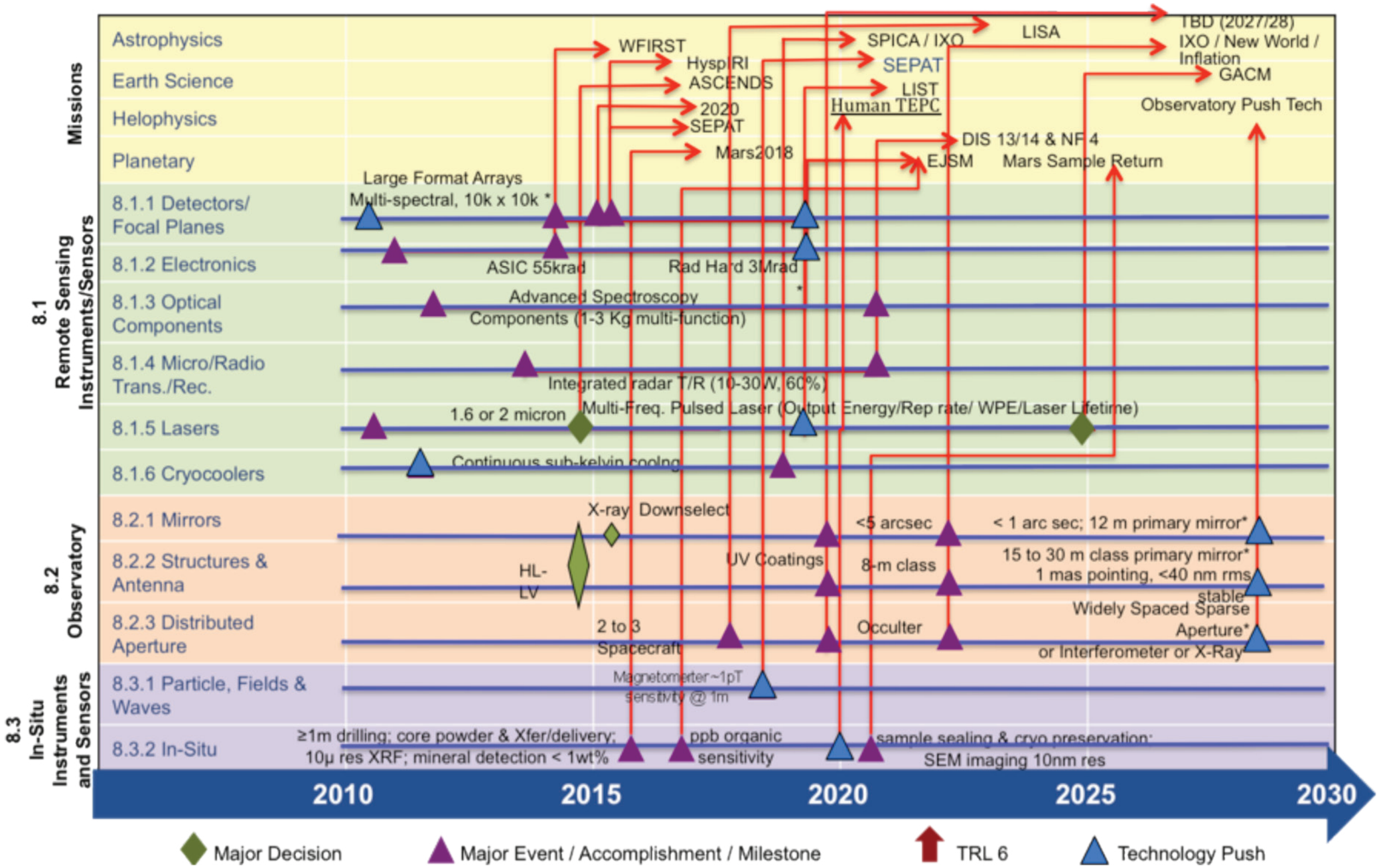


TA07

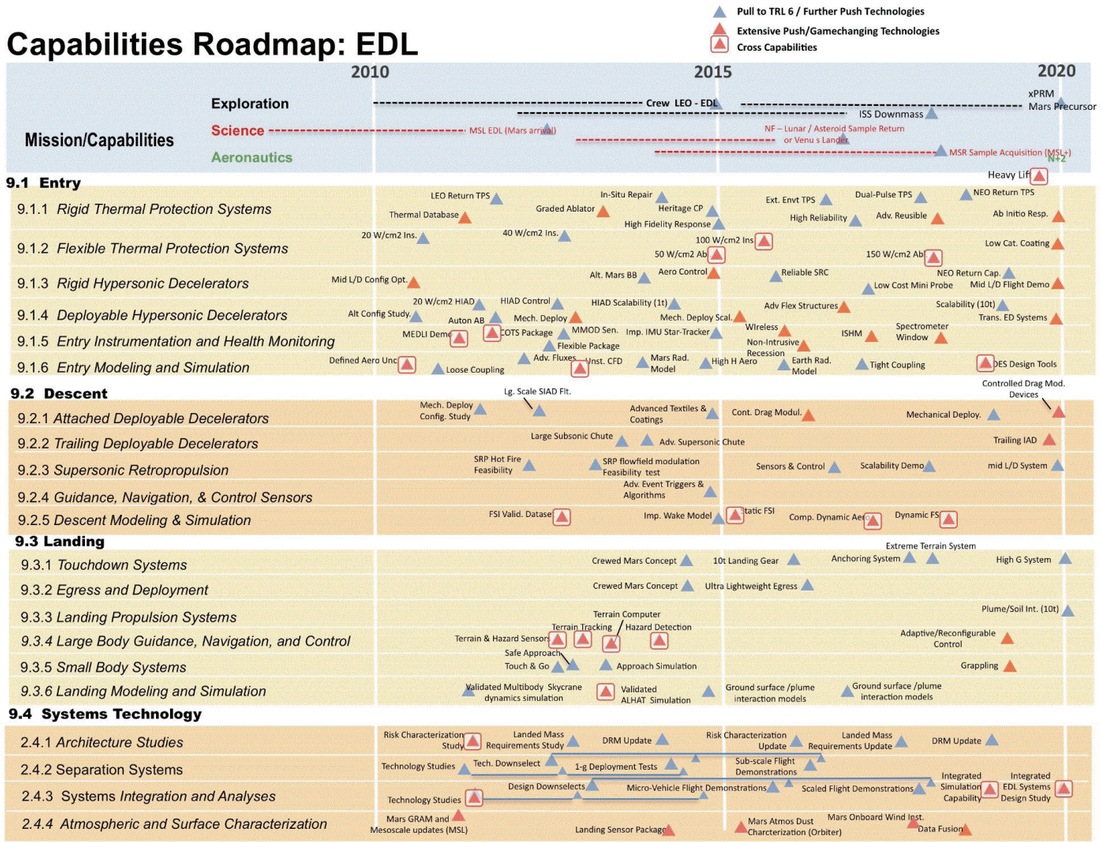
Technology Area 07: *Human Exploration Destination Systems Level-1 Technology Area Strategic Roadmap*

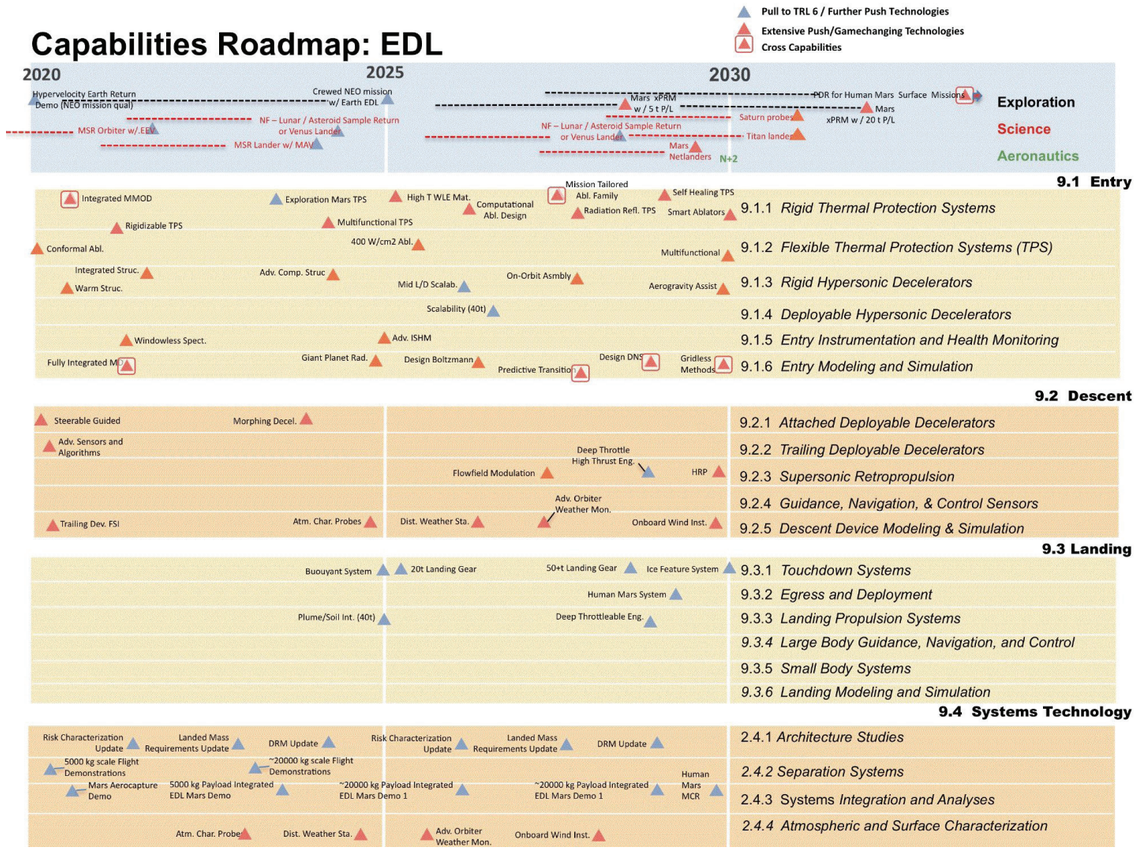


Technology Area 08: *SIOSS #8 Technology Area Strategic Roadmap*

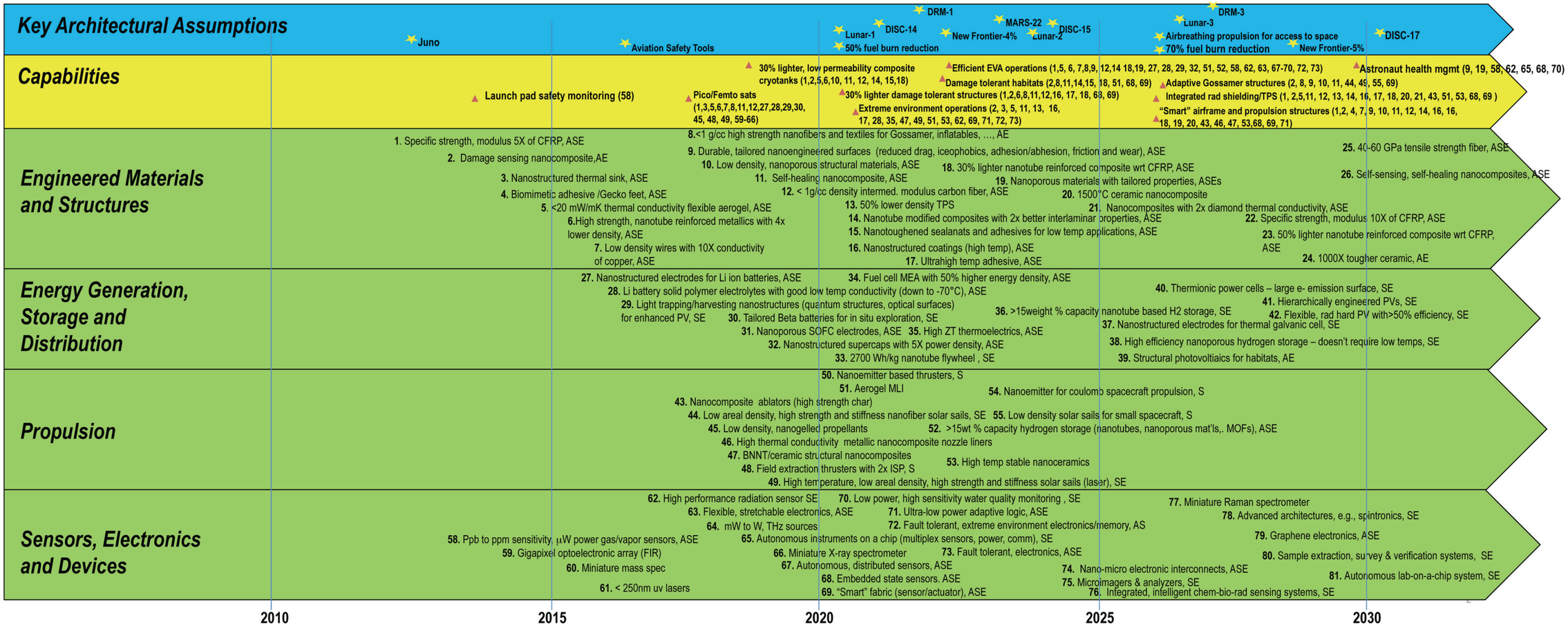


Technology Area 09: *Entry, Descent, and Landing Technology Area Strategic Roadmap (TASR)*

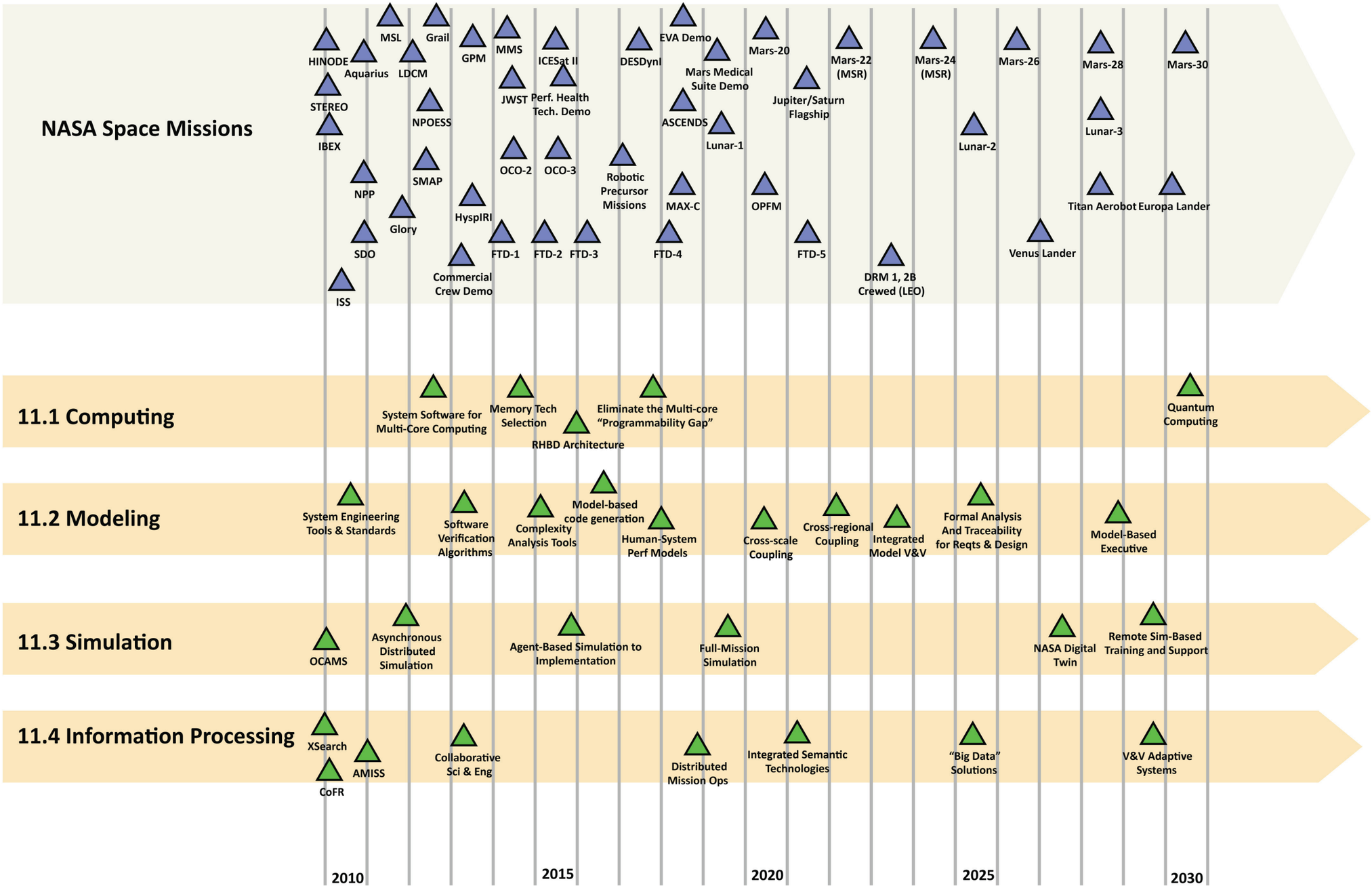




Technology Area 10: *Nanotechnology Technology Area Strategic Roadmap (TASR)*



Technology Area 11: *Modeling, Simulation, Information Technology and Processing Technology Area Strategic Roadmap (TASR).*



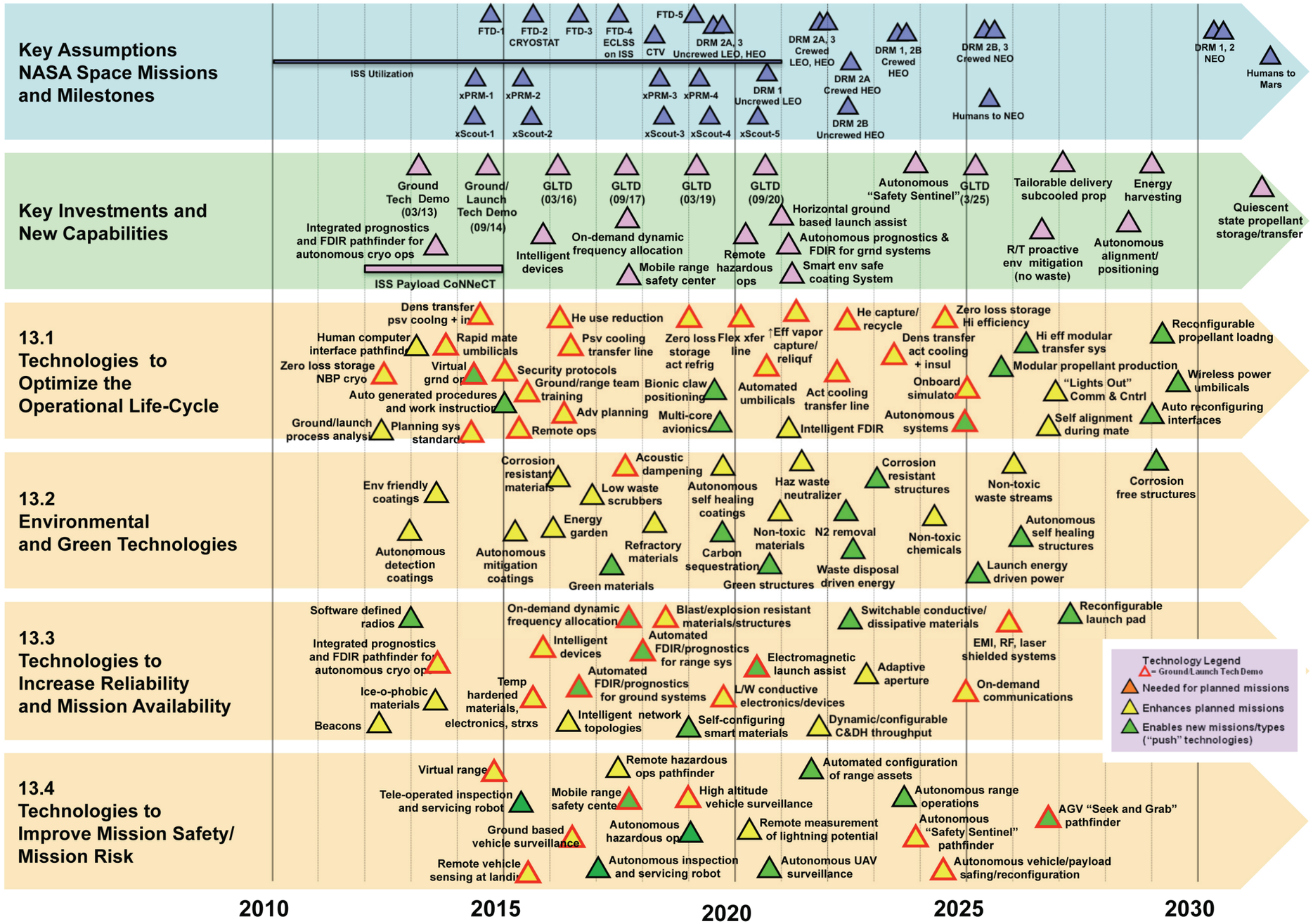
Technology Area 12: *Materials, Structures, Mechanical Systems, Manufacturing and Cross Cutting Strategic Roadmap*

Capabilities Roadmap: Materials, Structures, Mechanical Systems and Manufacturing

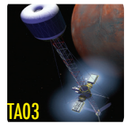
▲ Pull to TRL 6 / Further Push Technologies
★ Extensive Push/Game-changing Technologies
☆ Cross Capabilities

Capabilities	Selected Mission Architectures	2010	2015	2020	2025	2030
	Exploration Science Aeronautics	WFIRST	LEO Access Propellant Depot Radiation Protection NEO/Mars Precursor N+1 Explorer Augmentation	Heavy Lift LISA N+2	Advanced In-Space Propulsion IXO	Space Platforms N+3
2.1 Materials						
2.1.1 Lightweight Structure			Non-autoclave Composite ★; Hybrid Laminates ▲; Tailorable (spec. strength, therm. Cond.) ▲; Adv. Propulsion Materials ▲	▲ Hierarchical Structures (PMC-CMC-Metallic)	★ Multifunctional Structural (healing, sensing, shielding etc)	
2.1.2 Computational Design			Micro Design Models ▲; PMC Damage Models ▲; Environment (time dependent degradation) ▲; ★ Physics-based Lamina Models	★ Molecular Design (PMC); ★ Atomistic Design (Metals)	★ Physics Predictive Methods Damage Modes; ★→☆ Computationally Designed Materials → Virtual Digital Fleet-Leader	
2.1.3 Flexible Material Systems			Expandable Habitat ▲; Flex. EDL Materials ★	★ Solar Sail; Shape Morphing Materials ★	Adv. Expandable Materials ▲	
2.1.4 Environment			Cryo-Insulators ▲; Ad. Ablator ▲; Radiation/MMOD Protection ▲	Scavenging Materials ★; ▲ Advanced Insulators	▲ Ad. Refractory Composites	
2.1.5 Special Materials			Optical Materials (windows) ▲; Repair ▲; Sensor Materials ▲; Space Suits ▲; Impermeable PMC ★; Solid State Elec. Power	Autonomous Sensors ▲▲ Solid Oxide Fuel Cells; ★ Multifunctional Thin Films; ★ High Temperature Electronics		
2.2 Structures						
2.2.1 Lightweight Concepts			Non-Autoclave Primary Struct. ★; Composite Cryo Tanks ▲; Probabilistic Design Methodology ★; Composite/Inflatable Habitats ▲	▲ Expandable Struct. (Precision Mirrors & Solar/Antenna Arrays); ▲ Landers/Habitats; ★ Adaptive Structure		
2.2.2 Design and Certification Methods			Streamlined DAC Processes ▲; Composite Allowables ▲; ★ High-fidelity Response Simulation	★ Virtual Digital Certification; ▲ Landing → ★		
2.2.3 Reliability and Sustainment			Predictive Damage Methods ▲; Life Extension, Prediction ▲; SHM, THM Integration ★; In-situ Structural, Thermal Assessment ★	★ In-situ Structural/Thermal Repair → ★	★ Virtual Digital Fleet-Leader	
2.2.4 Test Tools and Methods			Integrated Flight Test Data ID and Usage ▲; Full-field Data Acquisition (non-contact) ★; Full-field Model V&V ★; Active Control of Structural Response ▲	★ Testing for Virtual Digital Certification → ★		
2.2.5 Innovative, Multifunctional Concepts			Integrated Cryo tank ▲; Integrated (non-pres) MMOD ★; Reusable Modular Components ▲; Integrated Window ▲; Integrated MMOD/ Radiation/Permeability ★	★ Integrated Pres w/ Thermal Control; ★ Integrated for High Temps	★ Integrated Adaptive	
2.3 Mechanical Systems						
2.3.1 Deployables, Docking and Interfaces			Restraint / Release Devices ▲; Common Universal Interchangeable Interfaces ▲; Deployment of Flex Materials ▲; Large Lightweight Stiff Deployable ▲	★ Precision Structure Deploy Mechanism; Mechanisms for Auto Precision Landing Hazard Avoidance		
2.3.2 Mechanism Life Extension Systems			Long Life Bearing/ Lube Systems ▲; Cryo Long Life Actuators ▲			
2.3.3 Electro-mechanical, Mechanical and Micromechanisms			Robotic Assembly Tools/Interfaces ▲; Cryogenic and Fluid Transfer ▲; Active Landing Attenuation System ▲; Relevant Environment Performance Testing (i.e.ISS) ▲	▲ New Concepts		
2.3.4 Design and Analysis Tools and Methods			Kinematics & Rotor Dynamics Analysis ▲; Precursor Flight High Rate Data for Design ▲	★ Interrelated Correlated Analysis System → ★	★ Virtual Digital Fleet-Leader	
2.3.5 Reliability / Life Assessment / Health Monitoring			Relevant Environment Durability Testing (i.e.ISS) ▲; Predictive Damage Methods ▲; Embedded Systems ★; Life Extension Prediction ▲	★ Integrated Systems → ★		
2.3.6 Certification Methods			Loads & Environments ▲; Test Verified Physics ▲; Probabilistic Design ▲	★ Digital Certification → ★		
2.4 Manufacturing						
2.4.1 Manufacturing Processes			Metallic Processes ▲★; PMC & MMC Processes ▲; CMC Processes ★; In-space Assembly, Fabrication and Repair ▲; Smart Materials Production ★			
2.4.2 Intelligent Integrated Manufacturing and Cyber Physical Systems			Model-based Supply Network ▲★; Virtual Process Conceptualization and Operation ▲; ★ Intelligent, Product Definition Model; ▲ Advanced Robotics	★ Cyber Physical Systems	★ Model-based Operations → ★ Virtual Digital Fleet-Leader	
2.4.3 Electronics and Optics Manufacturing Process			Photovoltaic ▲; Optics Fabrication ▲; ▲ Special Elec. Process	▲ Large Ultra-light Precision Optical Structures		
2.4.4 Sustainable Manufacturing			Affordability-driven Technologies ★; Environmental Technologies ▲; Green Production Processes ▲	★ Advanced Energy Systems		
2.5 Cross Cutting						
2.5.1 Nondestructive Evaluation and Sensors			NDE Complex Built-Up Structures ▲; Computational NDE ★; Combined NDE and Structural Analysis ★	★ Autonomous Inspection	★ Real-time Comprehensive Diagnostics → ★	
2.5.2 Model-Based Certification and Sustainment Methods			Physics-based design models ★; Strategies for Critical Component Reliability ★	★ Damage Prediction; ★ Integrated Life-cycle Analytical Tools	★ Physics-Based Reliability Prediction Methods and Damage Mitigation Processes for Virtual Fleet Leader → ★ Virtual Digital Fleet-Leader	
2.5.3 Loads and Environments			Combined Environments ▲; Test Validation ▲; Improved methods for Accurate Local and Global loads and Environments ★; Design for Monitoring Strategies ▲	▲ Mission Loads & Environments Monitoring	★ Autonomous In-flight Mitigation Strategies → ★	

Technology Area 13: *Ground and Launch Systems Processing Technology Area Strategic Roadmap (TASR)*



Technology Area 14: *Thermal Management Systems Technology Area Strategic Roadmap (TASR)*



TA01 • LAUNCH PROPULSION SYSTEMS

Solid Rocket Propulsion Systems
- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

Liquid Rocket Propulsion Systems
- LH_2/LOX Based
- RP/LOX Based
- CH_4/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

Air Breathing Propulsion Systems
- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Flyback Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment System
- Fundamental Air Breathing Propulsion Technologies

Ancillary Propulsion Systems
- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

Unconventional / Other Propulsion Systems
- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

Chemical Propulsion
- Liquid Storable
- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro-propulsion

Non-Chemical Propulsion
- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

Advanced (TRL <3) Propulsion Technologies
- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

Supporting Technologies
- Engine Health Monitoring & Safety
- Propellant Storage & Transfer
- Materials & Manufacturing Technologies
- Heat Rejection
- Power

TA03 • SPACE POWER & ENERGY STORAGE

Power Generation
- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fission
- Fusion

Energy Storage
- Batteries
- Flywheels
- Regenerative Fuel Cells

Power Management & Distribution
- FDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

Cross Cutting Technology
- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

Sensing & Perception
- Stereo Vision
- LIDAR
- Proximity Sensing
- Sensing Non-Geometric Terrain Properties
- Estimating Terrain Mechanical Properties
- Tactile Sensing Arrays
- Gravity Sensors & Celestial Nav.
- Terrain Relative Navigation
- Real-time Self-calibrating of Hand-eye Systems

Mobility
- Simultaneous Localiz. & Mapping
- Hazard Detection Algorithms
- Active Illumination
- 3-D Path Planning w/ Uncertainty
- Long-life Extr. Enviro. Mechanisms
- Robotic Jet Backpacks
- Smart Tethers
- Robot Swarms
- Walking in Micro-g

Manipulation
- Motion Planning Alg., High DOF Sensing & Control
- Robot Arms (light, high strength)
- Dexterous Manipul., Robot Hands
- Sensor Fusion for Grasping
- Grasp Planning Algorithms Robotic Drilling Mechanisms
- Multi-arm / Finger Manipulation
- Planning with Uncertainty

Human-Systems Integration
- Crew Decision Support Systems
- Immersive Visualization
- Distributed Collaboration
- Multi Agent Coordination
- Haptic Displays
- Displaying Range Data to Humans

Autonomy
- Spacecraft Control Systems
- Vehicle Health, Prog/Diag Systems
- Human Life Support Systems
- Planning/Scheduling Resources
- Operations
- Integrated Systems Health Management
- FDIR & Diagnosis
- System Monitoring & Prognosis
- V&V of Complex Adaptive Sys's
- Automated Software Generation
- Software Reliability
- Semi Automatic Systems

Auton. Rendezvous & Docking
- Rendezvous and Capture
- Low impact & Androgenous Docking Systems & Interfaces
- Relative Navigation Sensors
- Robust AR&D GN&C Algorithms & FSW
- Onboard Mission Manager
- AR&D Integration & Standardiz.n

RTA Systems Engineering
- Human safety
- Refueling Interfaces & Assoc. Tools
- Modular / Serviceable Interfaces
- High Perf., Low Power Onboard Computers
- Environment Tolerance
- Thermal Control
- Robot-to-Suit Interfaces
- Common Human-Robot Interfaces
- Crew Self Sufficiency

TA05 • COMMUNICATION & NAVIGATION

Optical Comm. & Navigation
- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

Radio Frequency Communications
- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- Flight & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

Internetworking
- Disruptive Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

Position, Navigation, and Timing
- Timekeeping
- Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

Integrated Technologies
- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

Revolutionary Concepts
- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQIF Microwave Amplifier
- Reconfigurable Large Apertures

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

Environmental Control & Life Support Systems & Habitation Sys.
- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation

Extravehicular Activity Systems
- Pressure Garment
- Portable Life Support System
- Power, Avionics and Software

Human Health & Performance
- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health & Performance
- Human Factors & Performance

Environmental Monitoring, Safety & Emergency Response
- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression
- Protective Clothing / Breathing
- Remediation

Radiation
- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

In-Situ Resource Utilization
- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing & Infrastructure Emplacement

Sustainability & Supportability
- Logistics Systems
- Maintenance Systems
- Repair Systems

"Advanced" Human Mobility Systems
- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

"Advanced" Habitat Systems
- Integrated Habitat Systems
- Habitat Evolution

Mission Operations & Safety
- Crew Training
- Environmental Protection
- Remote Mission Operations
- Planetary Safety

Cross-Cutting Systems
- Modeling, Simulations & Destination Characterization
- Construction & Assembly
- Dust Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

Remote Sensing Instruments / Sensors
- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

Observatories
- Mirror Systems
- Structures & Antennas
- Distributed Aperture

In-Situ Instruments / Sensor
- Particles: Charged & Neutral
- Fields & Waves
- In-Situ

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

Aeroassist & Atmospheric Entry
- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation & Health Monitoring
- Entry Modeling & Simulation

Descent
- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling & Simulation

Landing
- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling & Simulation

Vehicle Systems Technology
- Architecture Analyses
- Separation Systems
- System Integration & Analyses
- Atmosphere & Surface Characterization

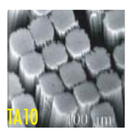
TA10 • NANOTECHNOLOGY

Engineered Materials & Structures
- Lightweight Structures
- Damage Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

Energy Generation & Storage
- Energy Storage
- Energy Generation

Propulsion
- Propellants
- Propulsion Components
- In-Space Propulsion

Sensors, Electronics & Devices
- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments



TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

Computing
- Flight Computing
- Ground Computing

Modeling
- Software Modeling & Model-Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science & Engineering Modeling
- Frameworks, Languages, Tools & Standards

Simulation
- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training & Decision Support Systems

Information Processing
- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

Materials
- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

Structures
- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

Mechanical Systems
- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

Manufacturing
- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

Cross-Cutting
- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

Technologies to Optimize the Operational Life-Cycle
- Storage, Distribution & Conservation of Fluids
- Automated Alignment, Coupling, & Assembly Systems
- Autonomous Command & Control for Ground and Integrated Vehicle/Ground Systems

Environmental and Green Technologies
- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

Technologies to Increase Reliability and Mission Availability
- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing & Telemetry

Technologies to Improve Mission Safety/Mission Risk
- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA14 • THERMAL MANAGEMENT SYSTEMS

Cryogenic Systems
- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

Thermal Control Systems
- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage

Thermal Protection Systems
- Entry / Ascent TPS
- Plume Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Space Technology Roadmaps STR • TABS
TECHNOLOGY AREA BREAKDOWN STRUCTURE